

1. List 4 factors that effect height of a wave system.

- wind strength: wind blows faster, more energy imparted to water and waves increase in size.
- wind duration: the longer that wind blows the higher the waves
- water depth: shallow water will produce higher waves than deep water.
- fetch: the area of water being influenced by wind.

2. You are the Master of a 20000 t ship heading up the Chesapeake for Baltimore. Wind is Force 7 from the west. Choices are eastern or western route up the bay in shallow water, or deep water route up center of the bay.

Force 7 wind  $\Rightarrow$  48-55 kt

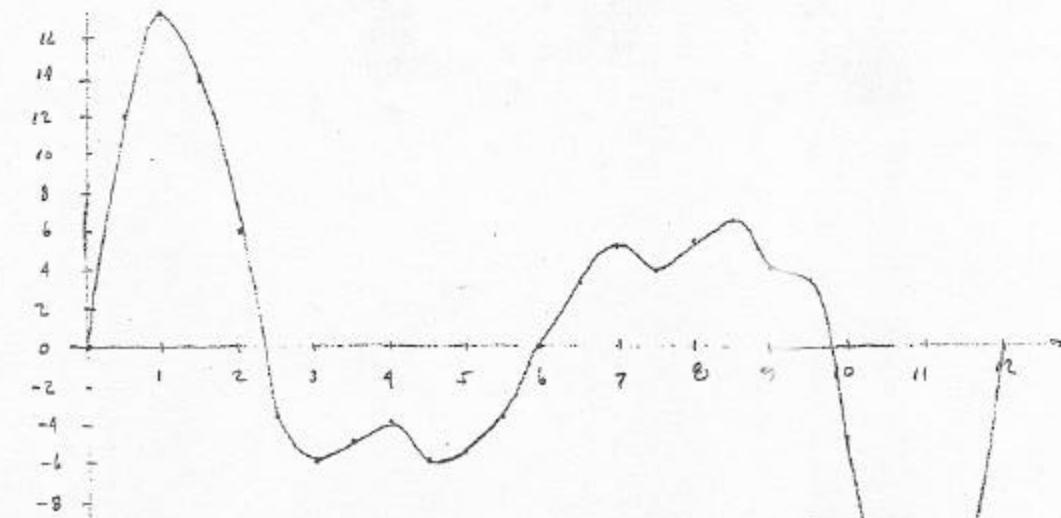
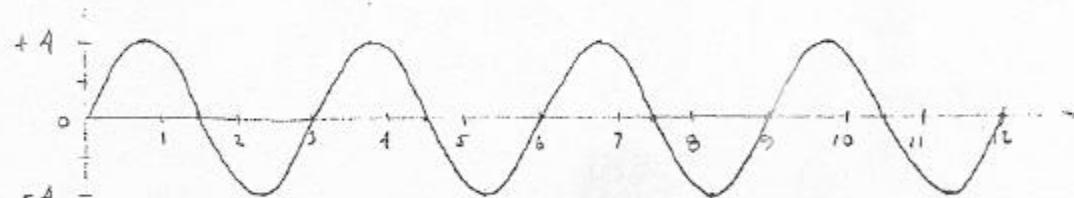
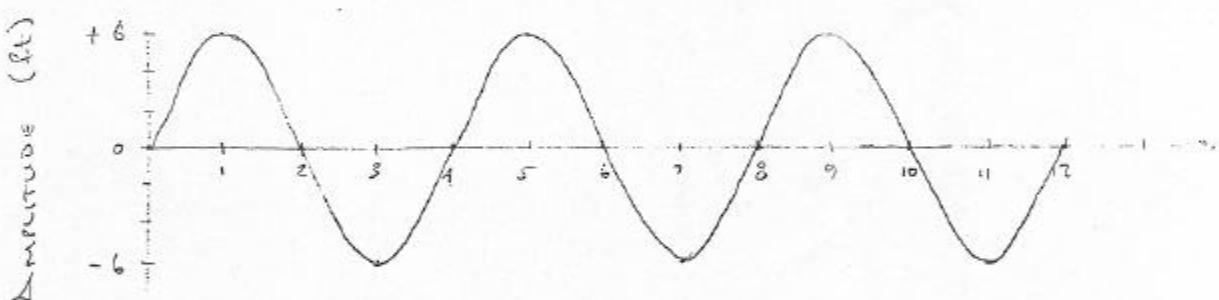
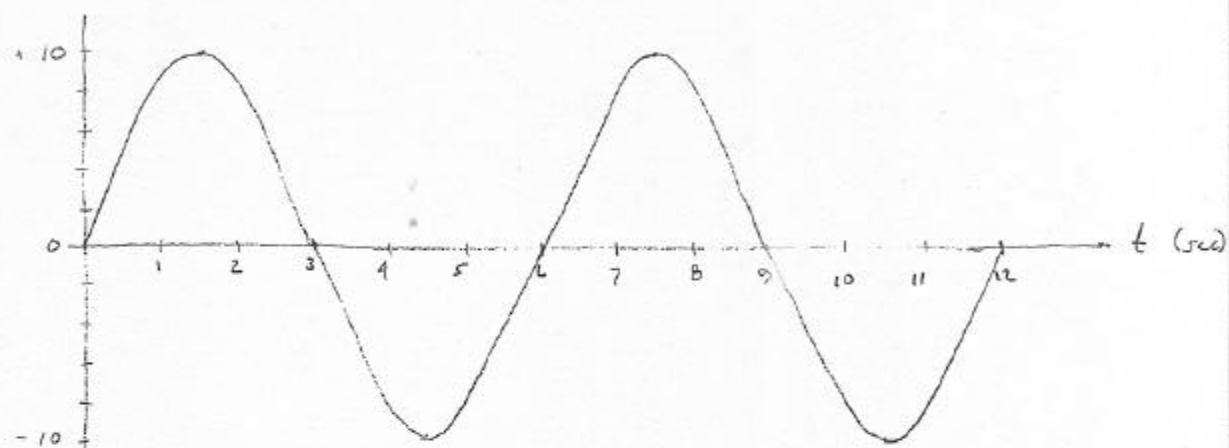
Option #1: anchor and wait for storm to pass

Option #2: deep water route in center of bay. Allows maneuvering room! 20000 t is a big ship.

Note: only 1 channel in Chesapeake Bay. 20000 t ship is HUGE!

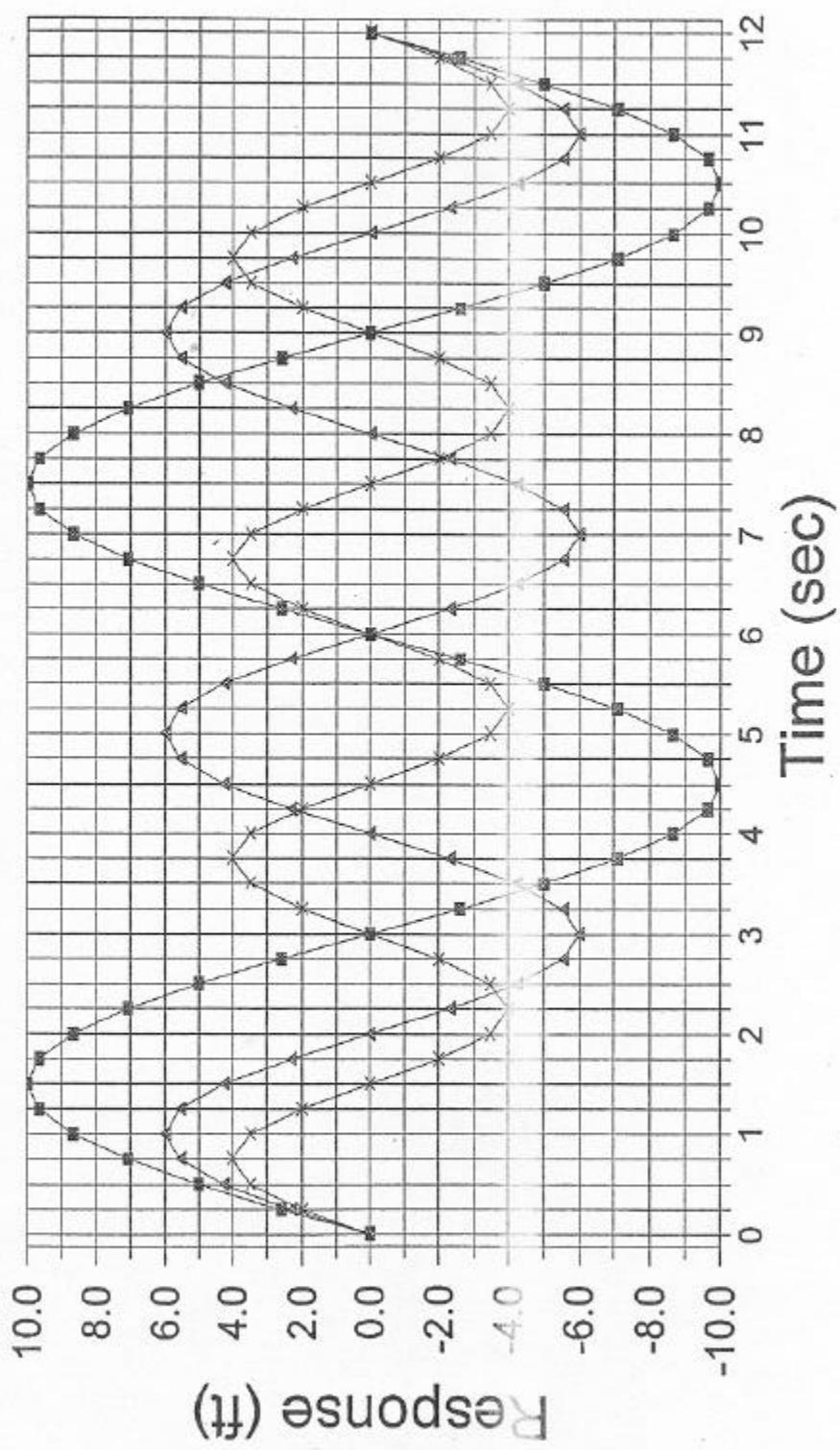
Plot the following wave patterns and then use Law of Superposition to find the combined wave pattern.

- amplitude 10 feet, period 6 sec
- amplitude 6 feet, period 4 sec
- amplitude 4 feet, period 3 sec



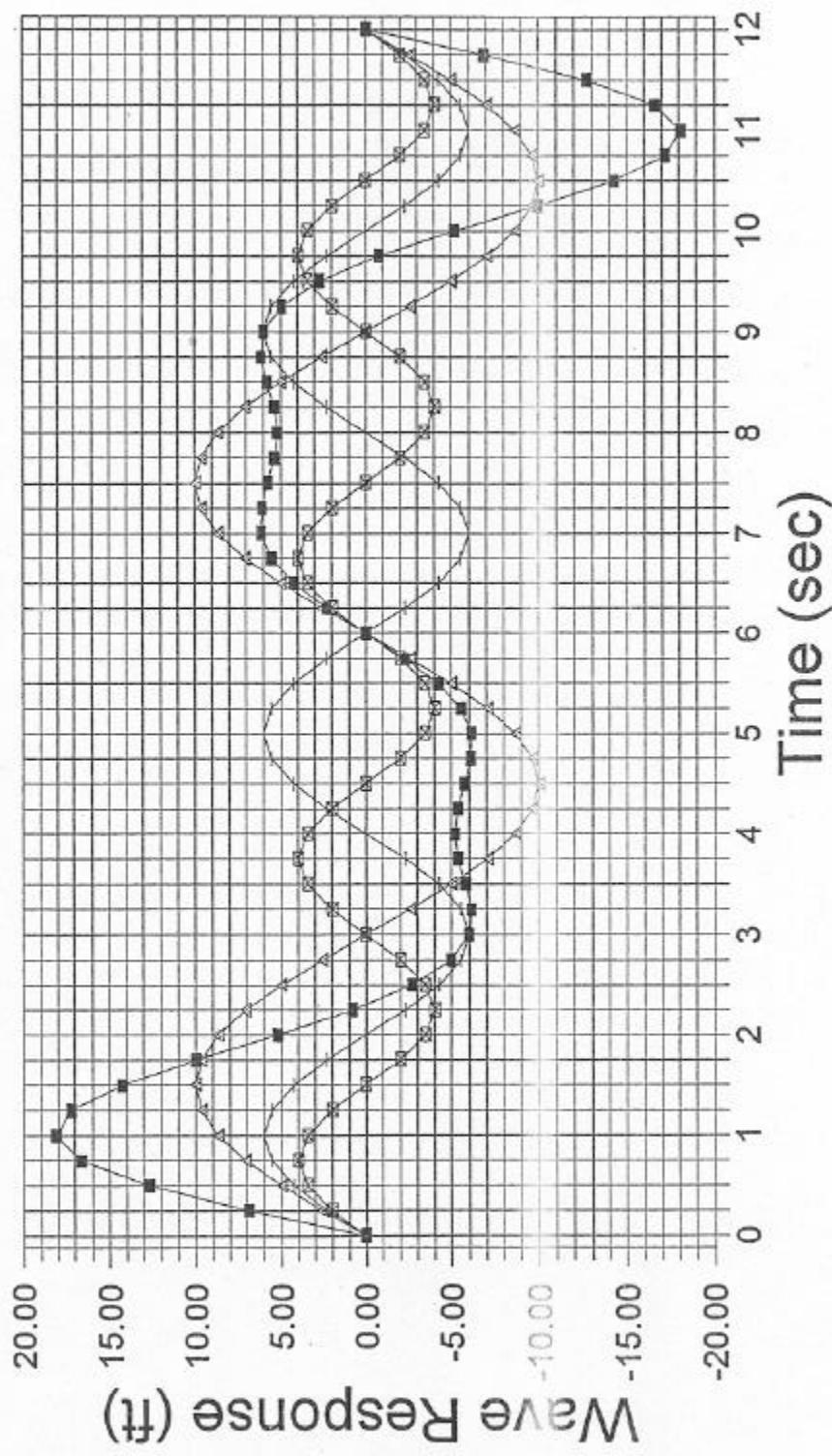
# PROBLEM 8-3

## WAVEFORMS



# **PROBLEM 8-3**

## **WAVEFORMS**



4. What are the 2 conditions necessary for simple harmonic motion?

- system must be linear. Magnitude of restoring force is proportional to the response.

i.e. simple spring-mass system.  $F = kx$

- restoring force must be in the opposite direction of the displacement.

5. Ship's resistance is countered by thrust generated by the propellers. Explain why surge motion for a ship is not simple harmonic motion.

- simple harmonic motion requires response to be proportional to the force being applied, and that force must oppose the direction of displacement.

- although resistance acts in opposite direction of thrust, once the force of propeller is removed, the ship slows to a stop without oscillatory motion.

6. An object is moving with simple harmonic motion.

- a) for motion to be maximized, what relationship must exist between object's motion and the forcing function?

$$z(t) = \frac{F}{K} \left[ \frac{1}{1 - (\frac{\omega}{\omega_n})^2} \right] \cos \omega t$$

- if  $\omega = \omega_n$ , then maximum response  
excitation and response are in phase

- b) what happens if magnitude of forcing function is doubled?  
magnitude of the response doubles

- c) what happens if frequency of forcing function is doubled?

as frequency increases, system response increases until maximum response is attained at  $\omega = \omega_n$ . When  $\omega > \omega_n$ , response decreases.

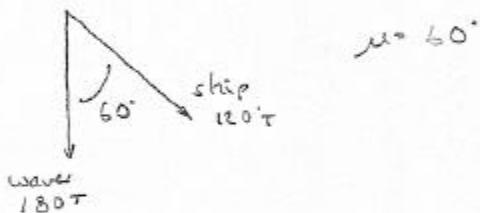
Ship on course 120°T at 16 kts experiences wave system heading due south waves have period of 5.2 sec and are 5 ft in height.

Calculate encounter frequency.

$$\omega_e = \omega_w - \frac{\omega_w^2 V_s \cos \mu}{g}$$

$$\omega_w = \frac{2\pi}{T} = \frac{2\pi}{5.2 \text{ sec}} = 1.208 \text{ rad/sec}$$

$$V_s = (16 \text{ kt}) (1.688 \frac{\text{ft}}{\text{kt}}) = 27.008 \frac{\text{ft}}{\text{s}}$$



$$\omega_e = 1.208 \frac{\text{rad}}{\text{s}} - \frac{(1.208 \frac{\text{rad}}{\text{s}})^2 (27.008 \frac{\text{ft}}{\text{s}}) (\cos 60^\circ)}{32.17 \frac{\text{ft}}{\text{s}^2}}$$

$\omega_e = 0.595 \frac{\text{rad}}{\text{s}}$

8. How does wave height affect response of a ship?

As wave height increases (magnitude of forcing function increase), ship's response motion will increase.

9. What wave conditions would produce a maximum response in a ship's structure.

resonance at  $\omega_c = \text{natural bending frequency}$ .

maximum response if wave length  $\approx L_{pp}$

10. Navigator on FFG-7 requires emergency surgery. Ship is in NATO sea state 8 and cannot conduct medevac. Operation can be done if ship motion is minimized. DCA recommends location 20 ft aft  $\Delta$  on deck close to waterline. Is this best location?

Sea state 8 = 37 ft seas, 60 kt wind

FFG-7: HMC (maybe) or HM1 and HMS

From curve of form:

LCF  $\approx$  24 ft aft  $\Delta$

operating draft  $\approx$  16 ft

Ship will pitch and trim roughly about F. So with F 24 ft aft of  $\Delta$  on waterline, choosing a location 20 ft aft  $\Delta$  near waterline is feasible.

choose course heading into seas and hang on!

Reality: 20 ft aft  $\Delta$  near waterline is messdeck or main engine room.

Ship has the following rigid body motion and structural frequencies:

$$\omega_{\text{heave}} = .42 \text{ rad/s}$$

$$\omega_{\text{longitudinal}} = .50 \text{ rad/s}$$

$$\omega_{\text{pitch}} = .53 \text{ rad/s}$$

$$\omega_{\text{torsion}} = .41 \text{ rad/s}$$

$$\omega_{\text{roll}} = .50 \text{ rad/s}$$

Ship is traveling at 12 kt directly into sea state 7. [25 ft seas]

a) calculate modal wave frequency

$$\omega_w = \frac{2\pi}{T_w} \quad , \quad \text{from Table 8.1 } T_w = 15 \text{ sec (sea state 7)}$$

$$\omega_w = \frac{2\pi}{15 \text{ sec}}$$

$$\boxed{\omega_w = .42 \text{ rad/s}}$$

b) comment on motion experienced by the ship.

- need to look at encounter frequency

$$\omega_e = \omega_w - \frac{\omega_w^2 V_s \cos \mu}{g}$$



$$\mu = 180^\circ \quad 20.26 \text{ deg}$$

$$\omega_e = .42 \text{ rad/s} - \left[ \frac{(.42 \text{ rad/s})^2 (12 \text{ kt}) (1.688 \text{ ft}) (\cos 180^\circ)}{(32.17 \text{ ft/s}^2) 5 \text{ kt}} \right]$$

$$\omega_e = .53 \text{ rad/s}$$

encounter freq is equal to  $\omega_{\text{pitch}}$  and very close to  $\omega_{\text{roll}}$ .

- ship will experience maximum pitching motion. Heave will also be present. Roll motion at a minimum.
- ship will also experience significant bending as  $\omega_e$  is close to  $\omega_{\text{longitudinal}}$

Note: slow to 7 kt, and  $\omega_e = .48 \text{ rad/s}$

\* increase to 15 kt,  $\omega_e = .56 \text{ rad/s}$

c) ship will alter course by  $45^\circ$ . Is this a smart move?



$$\omega_e = \omega_w - \frac{\omega_w^2}{g} \sqrt{1 - \cos \mu}$$

$$\omega_e = .42 \text{ rad/s} - \left[ \frac{(.42 \text{ rad/s})^2 (12 \text{ ft})(1.688)}{32.17} \right]$$

$$\omega_e = .497 \text{ rad/s}$$

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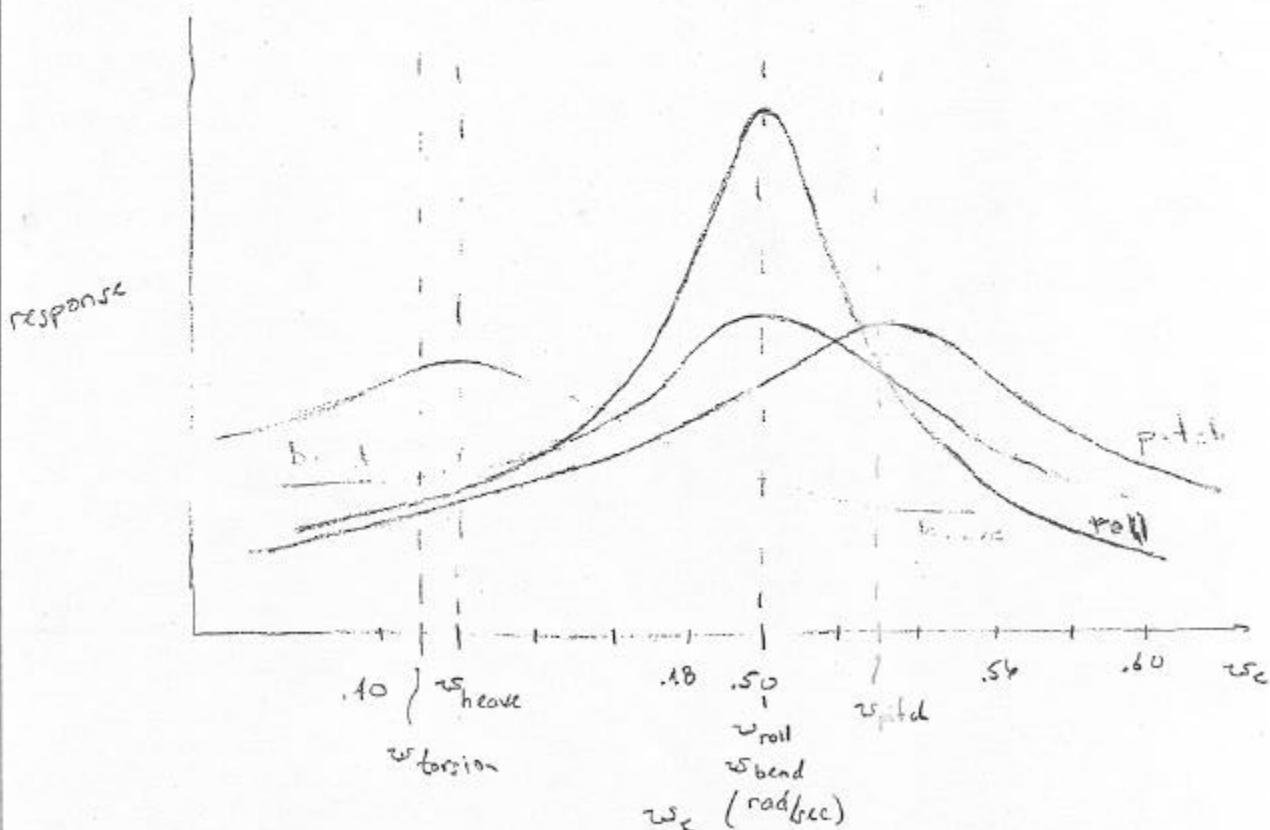
In this case,  $\omega_e$  is nearly equal to rolling and bending frequency.  
Also,  $\omega_e \approx \omega_{pitch}$ .

- Ship motion will be maximized in roll and close to maximum in pitch.  
In 25 ft seas this will be very uncomfortable and dangerous.

- Additionally, longitudinal bending response due to waves will be maximized since  $\omega_{longbend} = \omega_e$

$\Rightarrow$  Do NOT ALTER COURSE!

waves will also be attempting to turn ship (yawing)



Warship on course 090°T / 14 kt.

$$\begin{aligned} L_{pp} &= 165 \text{ ft} \\ \Delta &= 8000 \text{ t} \\ KG &= 19 \text{ ft} \end{aligned}$$

$$\begin{aligned} \omega_{heave} &= 1.17 \text{ rad/s} \\ \omega_{pitch} &= 1.07 \text{ rad/s} \\ \omega_{roll} &= 0.69 \text{ rad/s} \end{aligned}$$

$$\begin{aligned} \omega_{bend} &= 1.05 \text{ rad/s} \\ \omega_{torsion} &= 1.20 \text{ rad/s} \end{aligned}$$

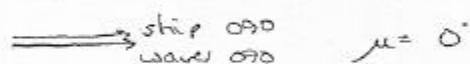
Ship is steaming waves from west,  $L_w = 450 \text{ ft}$ , height = 8 ft,  $T = 9.4 \text{ sec}$

a) encounter freq.

$$\omega_e = \omega_w - \frac{\pi^2 V_s \cos \mu}{g}$$

$$\omega_w = \frac{2\pi}{T_w} = \frac{2\pi}{9.4 \text{ sec}} = 0.668 \text{ rad/s}$$

$$V_s = (14 \text{ kt}) (1.688 \text{ ft/kt}) = 23.63 \text{ ft/s}$$

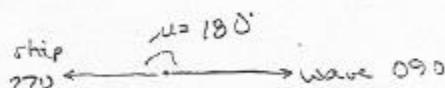
 ship 090  
wave 090  $\mu = 0^\circ$

$$\omega_e = 0.668 - \frac{(0.668)^2 (23.63 \text{ ft/s}) (\cos 0^\circ)}{32.17 \text{ ft/s}^2}$$

$$\boxed{\omega_e = 0.34 \text{ rad/s}}$$

Very little motion as  $\omega_e \ll$  natural frequencies.

b) ship on course 270°T.

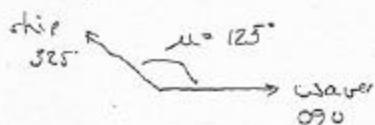
 ship 270  
 $\mu = 180^\circ$   
wave 090

$$\omega_e = 0.668 - \frac{(0.668)^2 (23.63 \text{ ft/s}) (\cos 180^\circ)}{32.17 \text{ ft/s}^2}$$

$$\boxed{\omega_e = 0.996 \text{ rad/s}}$$

Ship heading into seas and will be experiencing pitching and structural bending (especially with  $L_w \approx L_{pp}$ ).

- c) Ship turns into wind on CSE 325T. Is this a good course for flight operations?



$$\omega_e = 0.668 - \frac{(0.668)^2 (23.63 \text{ ft}) (\cos 125^\circ)}{32.17 \text{ ft/s}^2}$$

$$\boxed{\omega_e = 0.86 \text{ rad/s}}$$

Ship is at an angle to seas. Ship motion will be predominantly roll motion, but should not be too severe since we are not close to  $\omega_{roll}$ . 8 ft seas may cause problem, however.

- d) Ship is 4 hours ahead of PIM and recommendation to slow to 6 kt. Is this a good choice while still conducting flight ops?

Course remains 325T

$$V_r = (6 \text{ kt})(1.688 \text{ ft/kt}) = 10.13 \text{ ft/s}$$

$$\omega_e = 0.668 - \frac{(0.668)^2 (10.13 \text{ ft/s}) (\cos 125^\circ)}{32.17 \text{ ft/s}^2}$$

$$\boxed{\omega_e = 0.75 \text{ rad/s}}$$

Speed change will cause roll motion to increase because we closer to  $\omega_{roll}$ .

- e) As ship burns fuel, center of gravity rises. What happens to GM, stability, and roll response as fuel burned?

KG increases  $\rightarrow$  GM decreases  $\rightarrow$  stability decreases

$$\omega_{roll} \propto \sqrt{\frac{\Delta GM}{I_{xx}}} \rightarrow GM \text{ decreases, } \omega_{roll} \text{ decreases}$$

Troll increases

ship becomes more tender.

Amphib on 315°/14 kt while conducting flight ops.

$$L_{pp} = 580 \text{ ft}$$

$$B = 84 \text{ ft}$$

$$T = 19 \text{ ft}$$

$$D = 19,000 \text{ lb}$$

$$K_{M_r} = 25 \text{ ft}$$

$$KG = 21.3 \text{ ft}$$

$$\omega_{heave} = 0.94 \text{ rad/s}$$

$$\omega_{pitch} = 0.91 \text{ rad/s}$$

$$\omega_{roll} = 0.57 \text{ rad/s}$$

$$\omega_{bend} = 1.04 \text{ rad/s}$$

$$\omega_{torque} = 1.35 \text{ rad/s}$$

Wind from west at 10 kt

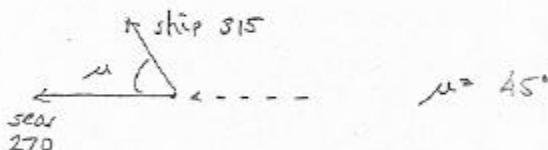
Seas from east. Height = 4 ft,  $L_s = 500 \text{ ft}$ ,  $T_s = 9.8 \text{ sec}$

a) encounter freq on current course.

$$\omega_e = \omega_w - \frac{\omega_w^2 V_r \cos \mu}{g}$$

$$\omega_w = \frac{2\pi}{T_w} = \frac{2\pi}{9.8 \text{ sec}} = 0.641 \text{ rad/s}$$

$$V_r = (14 \text{ kt}) (1.688 \text{ ft/kkt}) = 23.63 \text{ ft/s}$$



$$\omega_e = 0.641 - \frac{(0.641)^2 (23.63 \text{ ft/s}) (\cos 45^\circ)}{32.17 \text{ ft/s}^2}$$

$$\boxed{\omega_e = 0.427 \text{ rad/s}}$$

Ship may have some roll motion, but not much.  $\omega_e < \omega_{roll}$ .

- b) On 325°T, ship slows to 4 kt to launch LCAC. Is 325°T a good course?

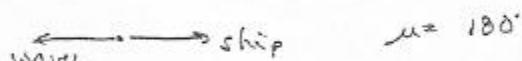
$$V_r = (4 \text{ kt}) (1.688 \frac{\text{ft}}{\text{kt}}) = 6.75 \frac{\text{ft}}{\text{s}}$$

$$\omega_c = 0.641 - \frac{(0.641)^2 (6.75 \frac{\text{ft}}{\text{s}}) (\cos 45^\circ)}{32.17 \frac{\text{ft}}{\text{s}^2}}$$

$\omega_c = 0.58 \text{ rad/s}$

Not a good course for LCAC or flight ops.  $\omega_c = \omega_{\text{roll}}$  and roll motion is maximized.

- c) Ship turns to 090°T, remaining at 4 kt. Calculate new  $\omega_c$ .



$$\mu = 180^\circ$$

$$\omega_c = 0.641 - \frac{(0.641)^2 (6.75 \frac{\text{ft}}{\text{s}}) (\cos 180^\circ)}{32.17 \frac{\text{ft}}{\text{s}^2}}$$

$\omega_c = 0.73 \text{ rad/s}$

Ship heading directly into seas. Very little motion as  $\omega_c$  not close to any natural frequencies of motion.

- d) While on 090°T, ship ballasts to draft of 21 ft to launch LCAC. Adding ballast lowers G,  $K_G = 20.3 \text{ ft}$ . Increasing draft floods well deck and reduces  $K_M = 21.6 \text{ ft}$ .

How has ballasting affected stability and roll response?

Before ballast,  $GM = 25 \text{ ft} - 21.3 \text{ ft} = 3.7 \text{ ft}$

After ballast,  $GM = 21.6 \text{ ft} - 20.3 \text{ ft} = 1.3 \text{ ft}$

Ballasting has caused decrease in GM and therefore a decrease in stability.

Decrease in GM will cause ship to become more tender, and roll period should increase.

$$\omega_{\text{roll}} \propto \sqrt{\frac{\Delta G_M}{I_{xx}}} \\ \propto \sqrt{\frac{\rho g \bar{V} G_M}{I_{xx}}} \\ \propto \sqrt{\rho g \frac{G_M}{B_N}}$$

} OPTIONAL TO EXPLAIN WHY  
ROLL PERIOD INCREASES

before ballast:

$$\omega_{\text{roll}} \propto \sqrt{\frac{\rho g (3.7 \text{ ft})}{K_M - K_B}}$$

$$\omega_{\text{roll}} \propto \sqrt{\frac{\rho g (3.7 \text{ ft})}{25 - K_B}}$$

$$K_B \approx T_c = 9.5 \text{ ft}$$

$$\omega_{\text{roll}} \propto \sqrt{\frac{\rho g (3.7 \text{ ft})}{25 - 9.5}}$$

$$\omega_{\text{roll}} \propto \sqrt{\frac{\rho g (3.7)}{15.5}}$$

$$\omega_{\text{roll}} \propto \sqrt{0.238 \rho g}$$

after ballast:

$$\omega_{\text{roll}} \propto \sqrt{\frac{\rho g (13 \text{ ft})}{K_M - K_B}}$$

$$\omega_{\text{roll}} \propto \sqrt{\frac{\rho g (13 \text{ ft})}{21.6 - K_B}}$$

$$K_B \approx T_c = 12 \text{ ft}$$

$$\omega_{\text{roll}} \propto \sqrt{\frac{\rho g (13)}{21.6 - 12}}$$

$$\omega_{\text{roll}} \propto \sqrt{\frac{\rho g (13)}{9.6}}$$

$$\omega_{\text{roll}} \propto \sqrt{0.135 \rho g}$$

roll freq decreases,  $\therefore$  roll period increases.

Cruise ship has following parameters:

$$L_{pp} = 930 \text{ ft}$$

$$B = 105 \text{ ft}$$

$$T = 32 \text{ ft}$$

$$\Delta = 47,000 \text{ t}$$

$$\omega_{roll} = 0.49 \text{ rad/s}$$

$$\omega_{pitch} = 0.72 \text{ rad/s}$$

$$\omega_{heave} = 0.71 \text{ rad/s}$$

$$\omega_{bend} = 1.10 \text{ rad/s}$$

$$\omega_{torsion} = 0.83 \text{ rad/s}$$

a) ship underway at 26 kt. Waves are 820 ft in length,  $T_w = 12.6 s$

calculate  $\omega_e$  for encounter angles of  $0^\circ, 45^\circ, 90^\circ, 135^\circ, 180^\circ$

$$\omega_e = \omega_w - \frac{\omega_w^2 V_s \cos \mu}{g}$$

$$\omega_w = \frac{2\pi}{T_w} = \frac{2\pi}{12.6 \text{ s}} = 0.498 \text{ rad/s}$$

$$V_s = (26 \text{ kt})(1.688 \frac{\text{ft}}{\text{kt}}) = 3.89 \text{ ft/s}$$

<u><math>\mu</math></u>	<u><math>\omega_e \text{ (rad/s)}</math></u>	<u>Motion &amp; structural response</u>
$0^\circ$	0.16	None
$45^\circ$	0.26	Hog or sag.
$90^\circ$	0.498	None
$135^\circ$	0.74	Heavy rolling
$180^\circ$	0.84	Pitch & heave, some roll torsion in structure.

b) ship slower to 13 kt in same waves as part (a). Calculate new  $\omega_e$ .

$$V_s = (13 \text{ kt})(1.688 \frac{\text{ft}}{\text{kt}}) = 21.9 \text{ ft/s}$$

$$\omega_w = 0.498 \text{ rad/s}$$

<u><math>\mu</math></u>	<u><math>\omega_e \text{ (rad/s)}</math></u>	<u>Response</u>
$0^\circ$	0.33	None
$45^\circ$	0.38	some roll
$90^\circ$	0.498	Heavy roll
$135^\circ$	0.62	Some roll, pitch and heave
$180^\circ$	0.67	Pitch and heave

c) Repeat (a) & (b) for ship operating in waves,  $L_w = 400 \text{ ft}$ ,  $T_w = 8.84 \text{ sec}$

$$\omega_w = \frac{2\pi}{T_w} = \frac{2\pi}{8.84} = 0.71 \text{ rad/s}$$

$$\text{Ship speed} = 26 \text{ kt} = 43.89 \text{ rad/s}$$

$$L_w = \frac{L_{PP}}{2}$$

<u><math>\mu</math></u>	<u><math>\omega_w (\text{rad/s})</math></u>	<u>Response</u>
0	0.02	None
45	0.22	None
90	0.71	Heave and some roll, pitch likely also close to bending resonance, but $L_w = \frac{1}{2} L_{PP}$
135	1.19	
180	1.40	harmonic of pitch and heave.

$$\text{Ship speed} = 13 \text{ kt} = 21.19 \text{ rad/s}$$

<u><math>\mu</math></u>	<u><math>\omega_w (\text{rad/s})</math></u>	<u>Response</u>
0	0.24	None
45	0.47	Heavy roll motion
90	0.71	Heaving and some roll
135	0.95	Structural torsion, some bending
180	1.05	Bending, but $L_w = \frac{1}{2} L_{PP}$

d) Repeat (a) and (b) for waves,  $L_w = 200 \text{ ft}$ ,  $T_w = 6.24 \text{ sec}$

$$\omega_w = \frac{2\pi}{6.24 \text{ sec}} = 1.01 \text{ rad/s}$$

$$\text{Ship speed} = 26 \text{ kt} = 43.89 \text{ rad/s}$$

$$L_w = \frac{L_{PP}}{4}$$

<u><math>\mu</math></u>	<u><math>\omega_w (\text{rad/s})</math></u>	<u>Response</u>
0	-0.38	wave overtaking ship.
45	0.02	None, ?
90	1.01	some roll maybe
135	1.99	None
180	2.4	None

$$\text{Ship speed} = 13 \text{ kt} = 21.19 \text{ rad/s}$$

<u><math>\mu</math></u>	<u><math>\omega_w (\text{rad/s})</math></u>	<u>Response</u>
0	0.34	
45	0.53	rolling motion, some pitch and heave
90	1.01	some roll, maybe
135	1.48	None
180	1.68	None

Small frigate,  $L_{pp} = 340 \text{ ft}$  on course 045° at 25 kt.

Sea from southwest ad period of 8.27 sec, height = 8 ft,  $L_w = 350 \text{ ft}$ .

for ship:

$$\begin{aligned}\omega_{heave} &= 1.03 \text{ rad/s} \\ \omega_{pitch} &= 1.21 \text{ rad/s} \\ \omega_{roll} &= 0.67 \text{ rad/s}\end{aligned}$$

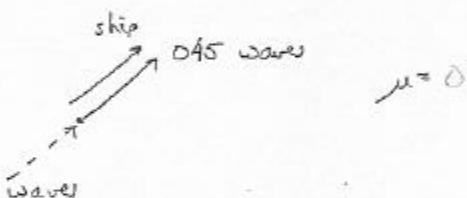
$$\begin{aligned}\omega_{beam} &= 0.75 \text{ rad/s} \\ \omega_{form} &= 1.12 \text{ rad/s}\end{aligned}$$

a) determine  $\omega_c$  on present course.

$$\omega_c = \omega_w - \frac{\omega_w v_s \cos \mu}{g}$$

$$\omega_w = \frac{2\pi}{T_w} = \frac{2\pi}{8.27 \text{ sec}} = 0.76 \text{ rad/s}$$

$$v_s = (25 \text{ kt}) (1.688 \frac{\text{ft}}{\text{kt}}) = 42.2 \frac{\text{ft}}{\text{s}}$$

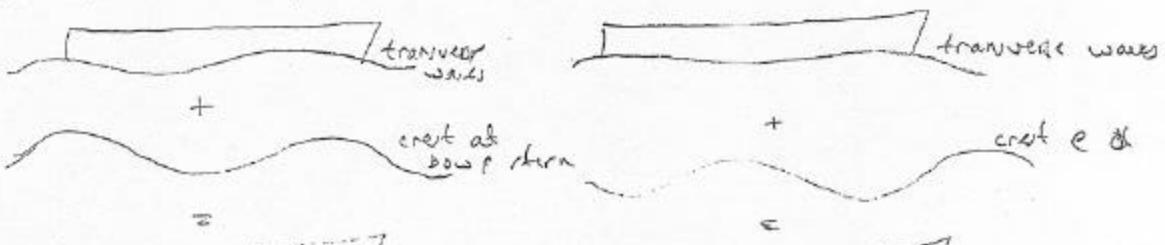


$$\omega_c = 0.76 - \frac{(0.76)^2 (42.2 \frac{\text{ft}}{\text{s}}) (\cos 0^\circ)}{32.17 \frac{\text{ft}}{\text{s}^2}}$$

$$\boxed{\omega_c = 0.002 \text{ rad/s}}$$

At this course & speed, ship is sitting on waves with no encounter freq. No response, however, severe hogging or sagging may result because  $L_w = L_{pp}$

- b) At this course & speed, waves are having a significant impact on power required to achieve 25 kt. At 25 kt, ship is in an area where wave-making resistance dominates, plus, ship is steaming with zero encounter frequency with waves approximately the same length as the ship. So, either large resistance, or small resistance as shown below.



16. Young ensign attempting to sleep complains that his rack is resonating at 110 Hz. Calls OOB and asks for course change so that encounter frequency changes, and rack stops resonating.

- 110 Hz  $\rightarrow \omega = 2\pi f = 691 \text{ rad/sec}$
- $\omega_e$  usually less than 1 rad/sec
- If ensign had paid attention in classes at USNA, would know that 110 Hz is indicative of machinery vibration
  - ↳ ship's electrical system operates at 60 Hz.
- what's this guy doing in his rack anyway?
- CO's standing orders do not authorize ensigns to direct course changes from his rack!

17. Describe one passive and one active anti-roll device commonly found on ships.

Passive - bilge keels

Active - fin stabilizers

Generally no anti-heave or anti-pitch devices because these motions are not as sensible.